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Test Results of the Astronaut Maneuvering Unit

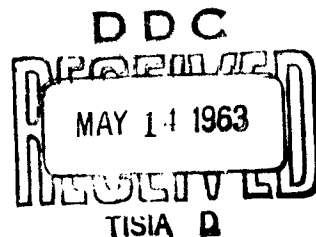
Peter N. Van Schaik

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Directorate of Aeromechanics
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Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report presents the results of a test program conducted by the Flight Accessories Laboratory, Directorate of Aeromechanics, Aeronautical Systems Division, under Project 8170 and Task 817008, "Space Maintenance Techniques." Mr. Peter N. Van Schaik was the project engineer for this program. Testing in a zero G environment began on 25 June 1962 and is still continuing.

The author wishes to acknowledge the assistance of many persons who have contributed to this program. From Flight Accessories Laboratory, Messrs. Chester May, Earl Washburn, and Lt Charles Kezar assisted in setting up and flying the pack. Captains Don Mueller and Mel Gardner of the Aerospace Medical Research Laboratories assisted in flying the pack and contributed to the analysis concerning human engineering. Mr. Don Griggs assisted in test planning and scheduling and the late Capt C. E. Kerr piloted the KC-135 aircraft. Both Mr. Griggs and Capt Kerr were from the Directorate of Flight Test.

The test model used in this report was manufactured by Chance Vought Corporation under Contract No. AF 33(616)-8197.

The movie film of the test is available from the Flight Accessories Laboratory.

ABSTRACT

The Astronaut Maneuvering Unit is a concept which provides man with the capability to translate between orbiting space vehicles while performing maintenance, assembly, and repairs.

To prove the feasibility of this concept an experimental pack was fabricated by the Chance-Vought Corporation and delivered to the Air Force for testing. The pack was flown on approximately 100 different parabolic trajectories by Air Force personnel in the KC-135 zero G aircraft. Tests were conducted to evaluate various parameters such as configuration, stabilization, maneuverability, and man-machine relationships. This report reviews the results of these tests.

This technical documentary report has been reviewed and is approved.

A handwritten signature in black ink, reading "John Tackis". The signature is fluid and cursive, with a large, sweeping initial "J".

JOHN TACKIS
Chief, Logistics, Maintenance and
Support Techniques Section
Support Techniques Branch
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INTRODUCTION

Maintenance of orbiting space vehicles will require man to leave his vehicle to perform "extra-vehicular" tasks. Man cannot make this exit at the end of a rope for he would find it extremely difficult to return to the mother vehicle (ref 1). Also, he would have no capability for maneuvering in space or for applying needed force to perform tasks outside the vehicle.

The AMU (Astronaut Maneuvering Unit, previously called Self-Maneuvering Unit, (figure 1) is an integrated package which fits on the astronaut's back and provides him with propulsion, stabilization, and life support. The type of configuration chosen and the functional subsystems in the pack were selected as a result of a feasibility study completed in January 1962 (ref 2). To verify the study results, an experimental operating model was fabricated under contract and delivered to the Air Force on 25 June 1962.

Tests of the model were performed in a zero G environment simulated in a KC-135 aircraft (ref 2). Results of the tests are presented in this report to provide guidance to all agencies working on this concept and to properly delineate the direction for future testing of this concept.

EXPERIMENTAL AMU PACK

General Approach

Ideally, an exact replica of the configuration and subsystems recommended in the study would have been preferred for full verification of the practicality of the AMU concept. However, operation of a hydrogen peroxide fuel in the narrow confines of the cabin of the KC-135 would be very dangerous and, therefore not permitted. Since the available test time is only 15 to 20 seconds — for test time is governed by the length of the route that the AMU will travel — the concept could be proved using a safer but less efficient fuel such as nitrogen. (The nitrogen would only reduce the traveling distance of the AMU pack.)

The experimental pack (figure 2) fabricated for this test program has the same configuration and operating functions as the unit finally recommended after testing except for the fuel, life support, and certain minor components used from regularly stocked items. Details of the experimental pack follow.

Configuration

The original pack was designed to fit conveniently on a man's back without interfering with the movement of his arms and legs. With the shoulder clamps, crotch nozzle, and waist belt, the pack is securely held to the man so that there is relatively no movement between the two. The top of the experimental pack was raised to form a crash bar to protect the operator's head during the zero G maneuvers. Later a secondary "roll bar" was added to further protect him from injury.

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Propulsion System

As mentioned previously, the experimental pack utilized cold nitrogen instead of hydrogen peroxide. The entire center of the pack contained a fiberglass-wound steel bottle for the fuel. The bottle had a capacity of 660 cubic inches when pressurized to 3500 psi. For the test, the pressure was reduced to 200 psi through regulators and expended through solenoid-operated nozzles (10) which were located identically to those in the design study (ref 3). The nozzles provided 20 pounds of thrust for fore-aft movements and 10 pounds for up-down movements.

Life Support

The life-support system was omitted on the experimental unit since it was not needed by the test participants and it was not necessary to prove the concept. It, along with the anthropomorphic space suit can be tested as separate items during tests later in the program. Additional tests must be conducted also to investigate the compatibility of the suit and the controller.

Stabilization

The stabilization system for the pack consisted of rate gyros located in each of the roll, pitch, and yaw axes. When the pack was rotated, the gyros generated an error signal which was fed through a preset-response network. The signal output from this network operated the proper solenoid and nozzle to correct the error. Nozzle operation was on the continuous alarm principle and, therefore, fired until the error was corrected.

Controller

The controller was a one-hand control located about the operator's waist on the waist belt. Rotational commands were separated from translational commands to prevent inadvertent actuation. The AMU operator would apply forward thrust for a period of time, then coast and make altitude corrections by up and down thrusts. The stabilization system maintained his orientation. The operator could command a rotation by actuating the control, thereby overriding the gyros. As soon as he released the control he would remain "fixed" at that attitude until the next command.

Included on the controller are two other controls requiring explanation. First is the "standby-command" switch. In the command position the gyros were connected into the circuit and generated the necessary signals to hold the man inertially stable. In the stand-by position, the gyros were disconnected but continued running. The stand-by position permitted the operator to move about without position corrections by the gyros.

The second control is a switch called "emergency-automatic". In the automatic position the gyros were a part of the circuit and performed as an autopilot. In the emergency position the gyros were disconnected and the operator had to fly the pack "open-loop" in all six degrees of freedom. This emergency switch incorporated in a space pack would give an astronaut an alternative action capability should a malfunction occur in the autopilot.

Power Supply

The power supply for the pack was 20 silver-zinc batteries located in the case. These batteries were divided to give a supply of ± 15 volts. Batteries were recharged between each maneuver and flight.

TEST PROGRAM

Subsystem Functions

The various parameters to be analyzed during the test program were:

- a. Pack configuration
- b. Nozzle location
- c. Controller design
- d. Maneuverability
- e. Stabilization
- f. Man-machine relation
- g. Operator judgment

One of the real difficulties in evaluating these parameters was the problem of recording technical data. During the test program, 16mm movies and comments by observers were used for data collection. A review of the film under slow motion and the test participants' comments accompanying the film assisted in judgments that were made concerning the degree of success attained in the tests.

KC-135 Test Aircraft

Navigation of the KC-135 aircraft was accomplished with the aid of closed-circuit television. The pilots of the aircraft were able to observe the AMU test operation taking place inside the aircraft cabin on the television screen.

The present Keplerian trajectory was used for the KC-135 aircraft. In this trajectory the available zero G time is approximately 32 seconds; however, due to the test procedure established for this program, most of this time could not be utilized.

Test Procedure

Assembled for testing, the experimental pack weighs 110 pounds. As the trajectory of the aircraft places a $2\frac{1}{2}$ G force on the test personnel both during pull-in and pull-out, safety of test personnel was the primary consideration. The weight of the pack could easily injure test participants during the $2\frac{1}{2}$ G's.

In the test procedure used, the pack was placed on the aircraft floor. The operator lay on top of the pack and strapped himself into it. As the aircraft approached zero G, two assistants helped the operator to an upright stationary position. As soon as the floating helmet (see next section) was released, the assistants released the pilot. From then on he had to depend upon himself for each maneuver. After the aircraft flew the trajectory and reached a 30-degree nose-down position the assistants grabbed the operator and pulled him to the floor regardless of mission accomplishment. This was necessary to prevent the operator from falling from the top of the cabin to the floor at $2\frac{1}{2}$ G's. The drawback to this procedure was that it reduced the "float time" to 15-20 seconds. Float time would ordinarily be approximately 30 seconds.

In most cases it was possible to fly two parabolas before the pack required refueling. Refueling was accomplished as the aircraft made the turnaround in preparation for a new maneuver.

Test Subjects

During the course of the test program, a total of seven subjects were used to operate and fly the pack. The history of these subjects as it relates to the pack varies considerably and is summarized in table 1.

TABLE 1
TEST SUBJECTS

OPERATOR	TIMES ON PACK	FLYING EXPERIENCE
A	34	PILOT
B	16	PASSENGER
C	22	PASSENGER
D	21	PASSENGER
E	3	PASSENGER
F	2	PASSENGER
G	2	PILOT
MISC.	20	
TOTAL	120	

FLIGHT TESTS

Aircraft Trajectory

Actual flying of the AMU pack proved to be difficult at times due to problems associated with the aircraft and its trajectory. When the aircraft was flown in a near perfect parabola, flying the pack down the cabin was relatively simple. However, the imperfect parabolas (the majority) nullified the pack test in most cases.

Thrust capability, F , of the pack was 20 pounds in the fore-aft direction and the weight, W , of the man and pack was $160 + 110 = 270$ pounds. Therefore, using the familiar

$$F = \frac{W}{G} a$$

we get

$$a = \frac{FG}{W} = \frac{20G}{270}$$

$$= .075 G's$$

The aircraft in most cases could be kept within ± 0.05 G's during a maneuver. But, this did not allow much tolerance between the capability of the pack and the aircraft. During the first few days of the test program, the aircraft's acceleration exceeded the pack's acceleration capability and prevented "translations" down the cabin. The pilots had been trying to fly the aircraft around the moving pack. This was very inadequate. A satisfactory solution was provided when a helmet was floated into the test area to serve as a reference point in establishing the flight parabola. The pilots then navigated the aircraft about the helmet instead of the AMU.

Translation Tests

The first week of testing was primarily devoted to contractor demonstration of pack performance and indoctrination of Air Force personnel in its operation. During parabolas 1 through 11, it was necessary to establish the recovery procedure and to adjust the gyro gains on the pack. The gyro gains were set on an air-bearing simulator prior to testing in the aircraft, but, customarily, all had to be reset to adjust to the actual zero G environment in the KC-135. (A small amount of friction inherent in air-bearing simulators produces slight inaccuracies.)

The object of the translational tests (figure 3) were to fly the pack from the net located at the center of the aircraft to the forward net, make a 180 yaw, and return to the starting point. Approximately 63 tests were run in this manner using all seven operators. The results were of varying degrees of success. Twelve straight translations and eight translations with 180-degree yaw were accomplished with very good success. The available zero G time proved to be too short to permit the complete cycle. The best that could be accomplished was the translation, turnaround, and partial return. Some of the problems uncovered during the translations, in addition to the aircraft problems, are as follows:

a. Considerable training is necessary before the operator can be successful in flying the pack. Although the switches on the controller were oriented in the direction desired, most operators became confused on which control to actuate. All operators were given instructions on the operation of the controls prior to the test but this proved to be inadequate. Either training flights or air-bearing simulator practice using the controller was necessary.

b. Many of the pack operators failed to make allowances for the aircraft rotation. Weightlessness began when the aircraft was in an approximate 45-degree nose-up position. At this time the gyros of the pack were engaged to hold the man stable, that is, inertially stable. During the trajectory the aircraft pitched from the 45-degree nose high to the 45-degree nose down, whereas the gyros were still restraining the man. As found in many of the tests, when the operator translated down the cabin he appeared to pitch feet-up by the time he reached the end of the cabin and was "plastered" face up against the ceiling. This in reality was because the axial position of the astronaut inside the aircraft cabin had not been properly synchronized with the pitch rate of the aircraft itself as it followed its parabolic trajectory. A small pitch down was required to successfully translate the cabin.

Although 30 successful translations out of 63 seems meager, two factors must be considered responsible for most of the poor flights. One factor, which has already been discussed, is the aircraft's accelerations during the flights. These accelerations slammed the operator against the cabin wall negating any possibility of data collection. The second

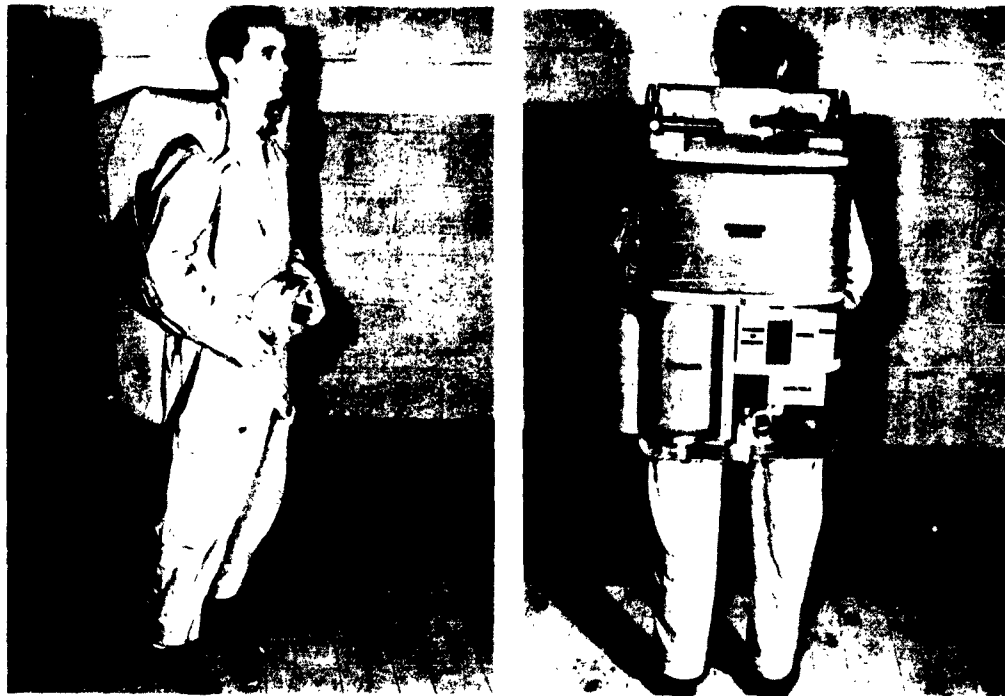


Figure 1. Mockup of Astronaut Maneuvering Unit, 13 December 1962

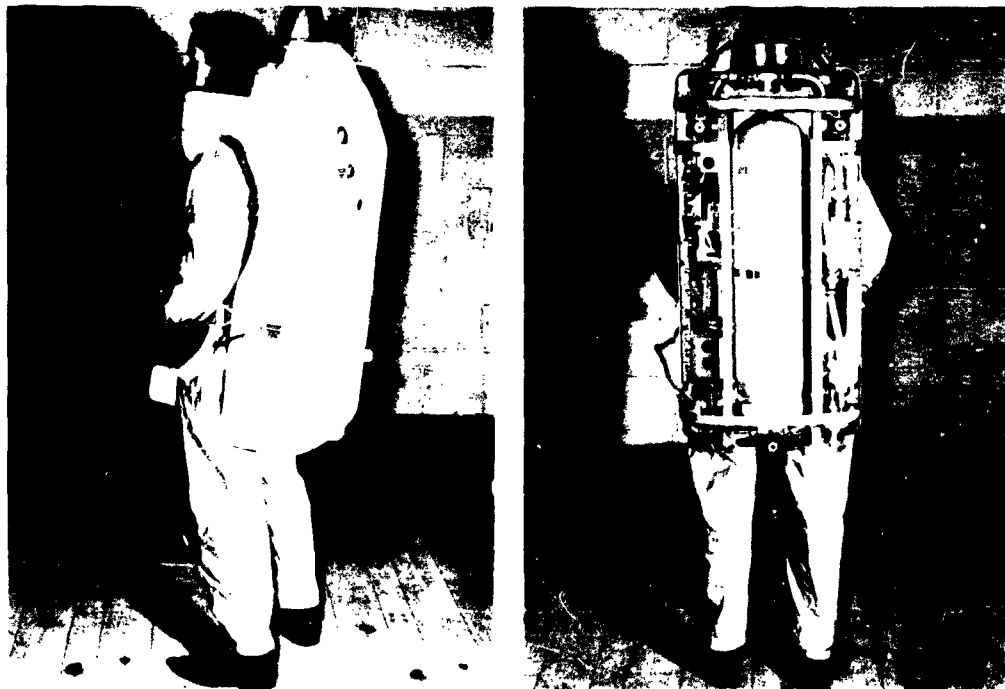


Figure 2. Experimental Version of Astronaut Maneuvering Unit for Testing in KC-135 Aircraft

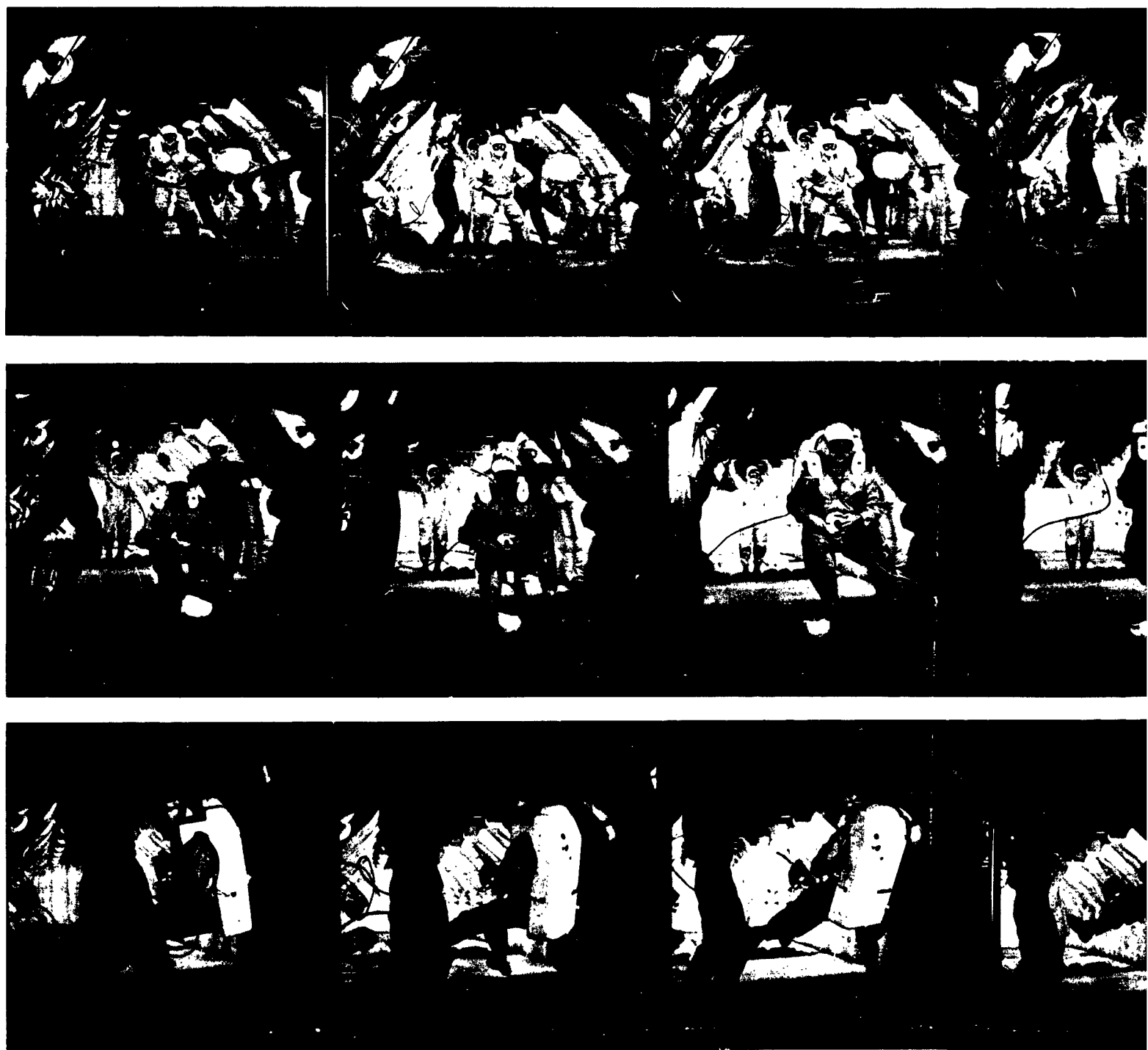


Figure 3. Transl

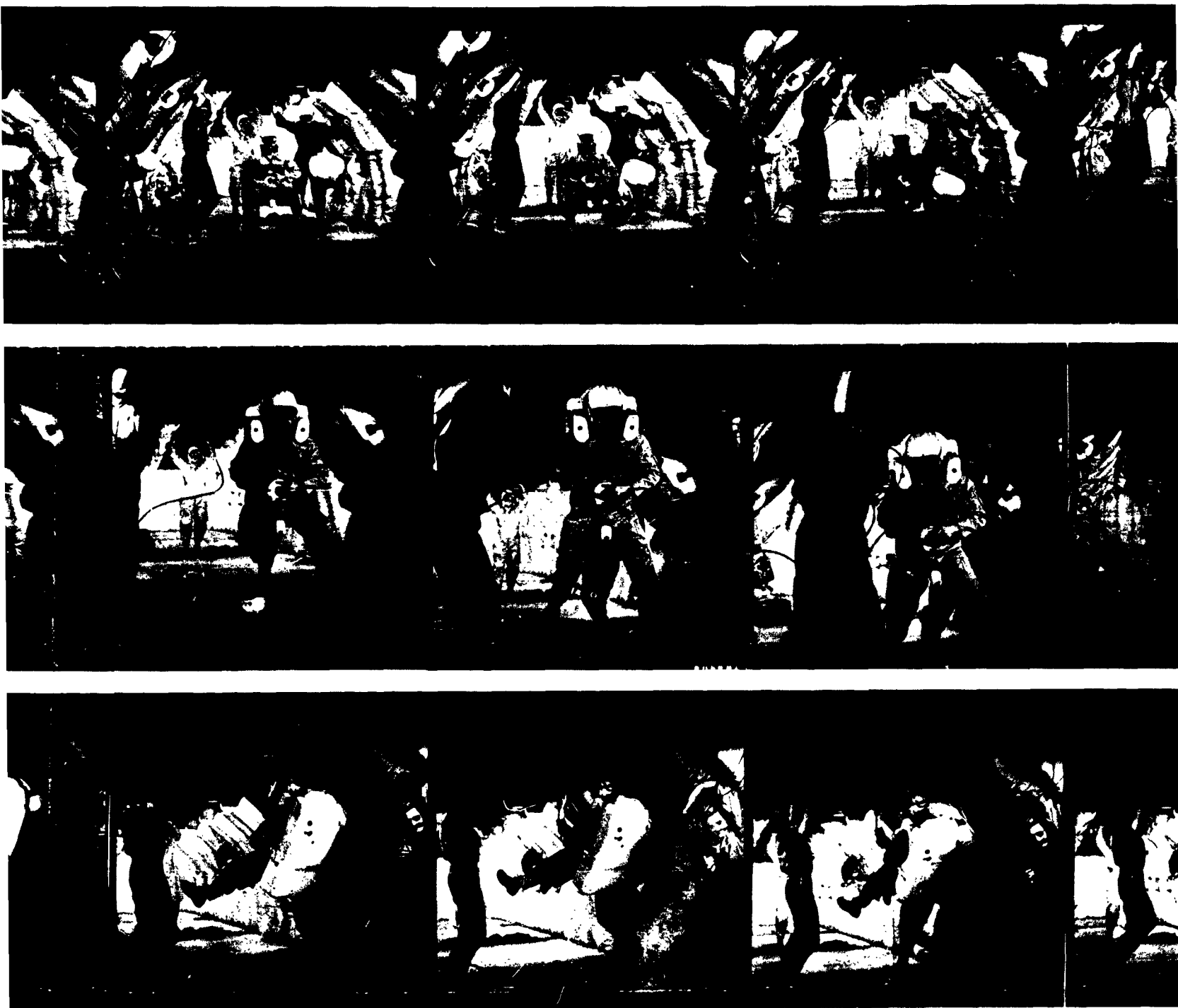


Figure 3. Translational Test with a 180-Degree Yaw Turnaround



Yaw Turnaround

factor was headroom clearance. The cabin of the KC-135 (figure 4) has a vertical clearance height of only $78\frac{5}{8}$ inches. Most pack operators were about six feet (72 inches) tall which left very little ceiling clearance. (Operation of the AMU would normally be performed in an approximate standing position.) A 30-foot translation was required; therefore, to be accurate within $\pm 3\frac{1}{2}$ inches vertically, was a difficult assignment, indeed.

During many of the translation tests, a comparison was made between flying the pack in manual (open loop) and in automatic mode. The AMU configuration afforded more control power for maneuvers in manual operation except in instances such as collisions with the cabin wall. Under manual operation after the pack struck the wall, a multi-axis tumble would result, but in the automatic mode the pack remained stable. Although this is not conclusive proof of the need for the autopilot, it does show its advantages.

Roll, Pitch, and Yaw Tests

Twenty-eight tests were run in roll, pitch, and yaw. These tests were made individually with no attempt at two or more simultaneously.

Attempts were made to rotate 360 degrees, stop, and return 360 degrees to the starting point. However, cabin space and aircraft accelerations proved to be insurmountable problems. In nearly all cases a 360-degree rotation could be performed satisfactorily, but collisions with the cabin ruined the remainder of the test.

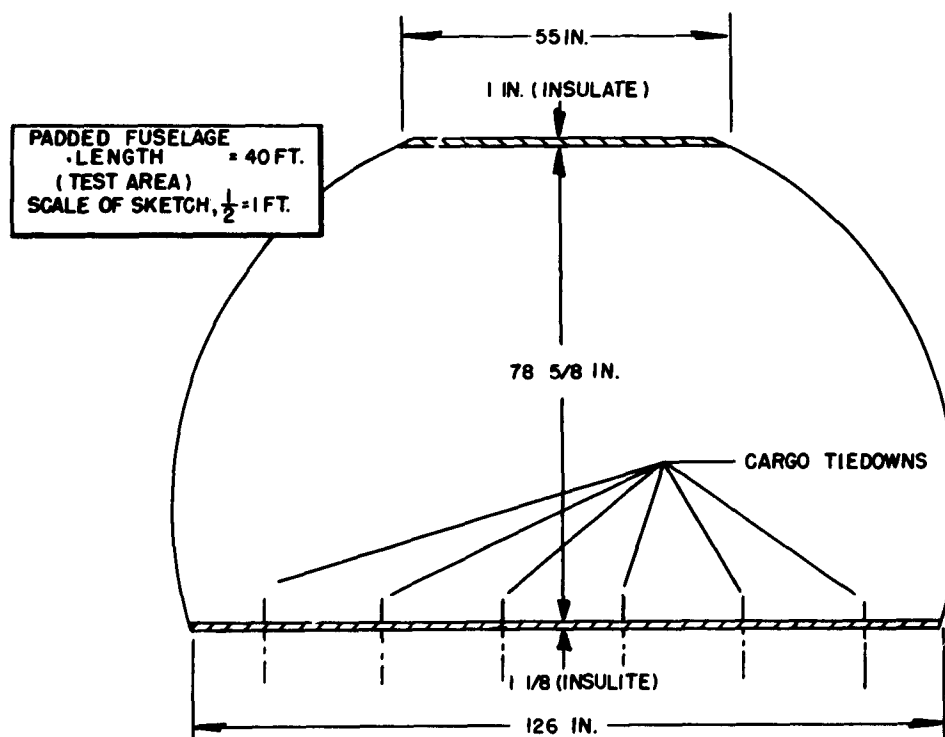


Figure 4. Cross Section of KC-135 Padded Fuselage with Zero G Environment

Tests were made in both manual and automatic modes. In most cases it was difficult to determine the success of the maneuver. However, several interesting observations could be made. In automatic, the maneuver was slower than in the manual operation, but once the man released the AMU controls the autopilot stopped and held him.

In manual, there was a tendency to exceed the prescribed speed. The operator would accelerate so fast he would pass 360 degrees before applying retro-thrust. Cross-coupling introduced roll and pitch during yaw maneuvers, and in most cases put the pack operator out of control. These motions were also introduced when the operator touched the cabin wall with his feet.

Tumble Recovery

Four tests were performed to determine the ability of the man to recover from a multi-axis tumble. For these tests, two assistants would spin the man (about an axis inclined to the operator's yaw, pitch, and roll axes) just after zero G occurred. The pack operator would then try to stop the rotation and return to an upright position.

In the automatic mode, the command-standby switch had to be in the standby position to take the gyros out of the circuit. Recovery from tumble was by far simpler in this mode because it required the operator to push the switch from standby to command, thereby bringing the tumbling pack to a halt. The pack operator then had to reorient himself.

In the manual mode (open-loop), recovery was more difficult but it was accomplished. Since the operator knew in which two directions he was going to be spun, he could mentally determine what controls to operate. Consequently, before he had made one revolution, the proper corrective thrusts were on to stop him.

Control Pole

The controller used for the majority of the tests is a one-hand control (figure 1). However, due to the short test time (15 seconds), decisions for corrective action had to be fast and as a result the operators used two hands.

To evaluate a different type of control, the contractor loaned a one-hand, five-degree-of-freedom control "pole" for tests. This control was tested on five maneuvers, but was broken after the first and fifth tests. Although five maneuvers were not satisfactory to fully test the control pole, the films showed that an operator can fly away from the cabin wall with it easier than with the other type of controller. Obviously, more testing is necessary.

OBSERVATIONS AND CONCLUSIONS

The flights made to date with the pack make possible the following conclusions from a review and analysis of the test comments and test films:

- a. The configuration of the pack is satisfactory in its current design. Tests have shown that it does not interfere with the operator's arms or legs while he flies and maneuvers the pack. The pack, however, must either be made adjustable for the various heights of astronauts or be custom-made for each individual.

b. The thrust levels of 20 pounds for fore and aft maneuvers and 10 pounds for up and down maneuvers can easily be handled by the pack pilot. In the manual mode, test pilots stated that the thrust levels gave "a firm push." It was their opinion that 30 pounds fore-aft thrust would probably be more advantageous and yet would retain the ease of handling already attainable with the pack.

c. The nozzle location provided excellent control of the pack. The arrangement minimized thrust misalignment due to shift of the operator's center of mass and, therefore, made open-loop operation of the pack simpler.

d. The autopilot stabilization system performed satisfactorily in principle but needs modifications and additional testing to be optimum for space. Two approaches are possible for testing: (a) a pulse-width modulation amplification system which would simplify the setting of the gyro gains and prevent the pack from oscillating, and (b) a means of disconnecting the autopilot when forward thrust is applied but a capability of keeping it on while coasting or standing still. As the autopilot would not be making attitude corrections, more thrust would be available for forward translations. That stabilization is necessary to keep control of the man and pack for success in this endeavor is a definite criterion. It may well be that as man becomes more proficient in operation of the pack, stabilization may be a secondary or supporting factor rather than the primary system. The addition of a fourth nozzle on the AMU pilot's back will provide better control of the pack because of the resultant symmetrical design and the possibility that it will conserve fuel. The inclusion of a deadband of about ± 10 degrees in the stabilizing capacity of the gyros will also provide for fuel economy.

e. The controller was one of the most difficult items to evaluate during the testing for it was much easier to judge its performance in the test environment than to predict its application in space. Analysis of the film showed that the biggest factor in causing the controller to appear inefficient was time: time to make a decision; time to get from one control to another. This time element is the short 15 seconds of the test imposed by the limited KC-135 cabin space. The opinion, of the test participants is, however, that the current controller may be satisfactory in space because it will not be crowded by the time element which governed decisions in the test. For further testing in the aircraft other controllers such as the "one-hand control pole" offer more promise for future development.

f. Training of AMU pack operators is definitely required. It should include not only a familiarization with control movements but also a "feel" of pack moving and turning power. During the tests the command responses of an untrained operator were slow and sometimes inaccurate. This was true even with untrained operators who were trained pilots.

g. More testing is required to ascertain the factors needed to improve the operator's judgment during rendezvous. During the straight translations with a 180-degree turn-around, operators made the turnaround before they had taken out the forward velocity component. As a result, the operator hit the forward test area flying backwards.

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To prove the feasibility of this concept an

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experimental pack was fabricated by Chance-Vought Corp. and delivered to the Air Force for testing. The pack was flown on approximately 100 different parabolic trajectories by Air Force personnel in the KC-135 zero G aircraft. Tests were conducted to evaluate various parameters such as configuration, stabilization, maneuverability, and machine relationships. This report reviews the results of these tests.

1. Astronautics
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3. Space Flight
4. Satellite Rendezvous Vehicles

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